

PULSED POWER SWITCHING OF 4H-SiC VERTICAL D-MOSFET AND DEVICE CHARACTERIZATION

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Abstract

The purpose of this research is to characterize and compare CREE's new N-Channel Silicon Carbide (4H-SiC) vertical power D-MOSFET with CREE's previous generation of N-Channel Silicon Carbide (4H-SiC) vertical power D-MOSFET. Changes made to the newest MOSFET design lead to a 400% increase in pulsed current handling capability over the previous generation device with the same active area.

I. INTRODUCTION

CREE's new generation of D-MOSFET are rated for 1200V and 150A continuous; the previous generation D-MOSFET is rated for 1200V and 80A continuous. The active conducting area (0.40 cm^2) and chip size (0.56 cm^2) are identical in the two generations. The devices were tested on a RLC ring down low inductance test bed [1]. Both generations of 4H-SiC D-MOSFETs were tested with a gate-to-source voltage of 20V and 1200V drain-to-source using multiple gate resistances. Single and repetitive pulse switching was utilized for testing the devices. The tests consisted of up to 2000 shots at a repetition rate of 1Hz. Throughout the testing, the devices were removed from the RLC ring down test bed and characterized on an Agilent B1505A curve tracer. Results gathered include: characteristic curves, transient pulse characteristics, stress failure points, device degradation, and device performance. The transient response of the 150A devices were analyzed using different external gate resistances for the purpose of switching performance optimization.

II. PREVIOUS GENERATION SiC MOSFET

This generation of CREE's SiC MOSFET devices rated for 1200V and 80A were initially labeled 54-78, 54-88 and 54-910 for identification purposes. The tests started with the initial characterization of the device labeled 54-

78 in the curve tracer. The initial characterization was conducted in order to gather data for drain-to-source breakdown voltage, transfer characteristics and output characteristics. The initial characterizations for this device are shown in Figure 1, Figure 2, and Figure 3.

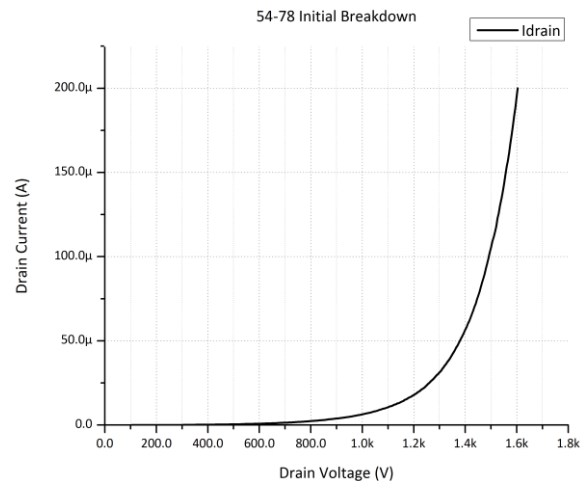


Figure 1. Initial drain-to-source breakdown voltage for the 54-78 MOSFET.

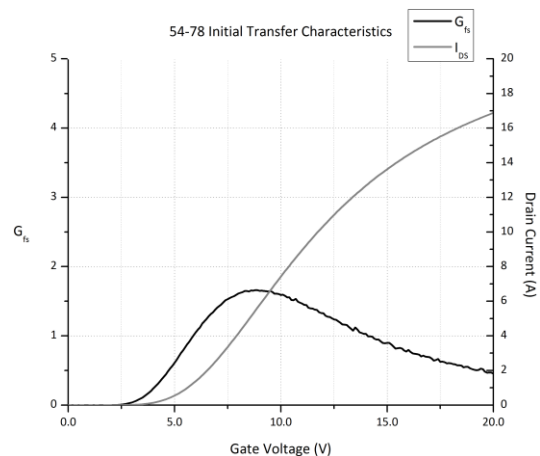


Figure 2. Initial transfer characteristic curve for the 54-78 MOSFET.

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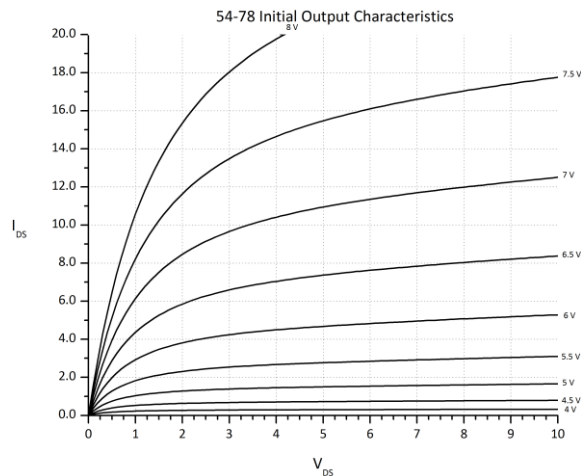


Figure 3. Initial output characteristic curves for the 54-78 MOSFET.

After initial characterization the MOSFET was pulsed for one thousand shots with an external gate resistor of 3.3 Ohms and drain-to-source voltage of 1200V. Using 1200V drain-to-source the ring down test bed produced a 268.4A current through the MOSFET with a di/dt of 536.4A/μsec. The device was subjected to one thousand shots and characterized in the curve tracer once more. Figure 4 shows the last shot's waveforms of the first series. The switching energy dissipation was 15.3 mJ.

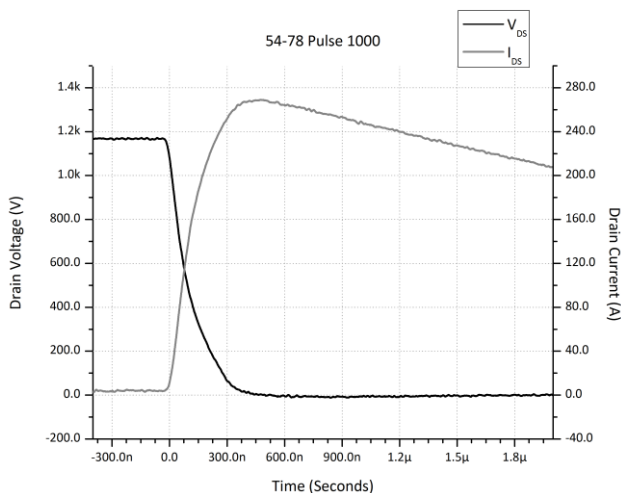


Figure 4. Shot number 1000 for the 54-78 device.

Some degradation was encountered in the drain-to-source breakdown voltage. The breakdown voltage degraded from 1200V to 1025V which is equivalent to 14.5% degradation. Even though the breakdown voltage degraded, the output and transient characteristic curves remained the same.

The test was repeated for another one thousand shots and the device was characterized once more. This time the device's breakdown voltage suffered a much milder

degradation of 7.3% referenced to the device's last degraded result. The output and transient characteristic curves remained unaffected once again.

This device started to show large leak currents when it was characterized after the first 3000 shots. Figure 5 shows the drain-to-source breakdown voltage waveforms produced by the device during characterization.

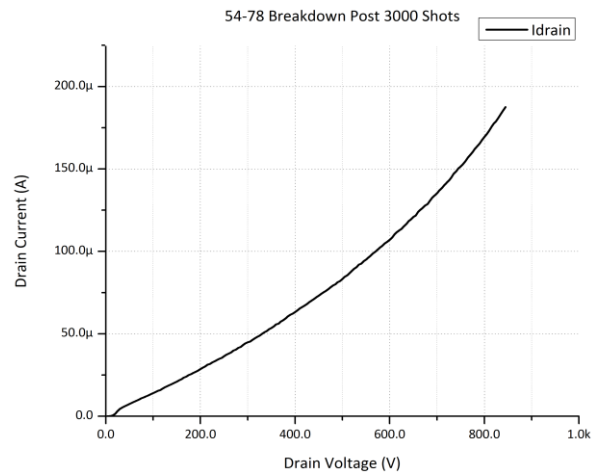


Figure 5. 54-78 device drain-to-source breakdown voltage after 3000 shots.

In total this device was tested for approximately 8000 pulses. The device failed into a short a few pulses after 8000. The forward characteristics remained the same during testing until failure. However, the breakdown voltage degraded consistently with each set of pulses. Figure 6 shows the comparison between initial forward characterization and post-5000 characterization.

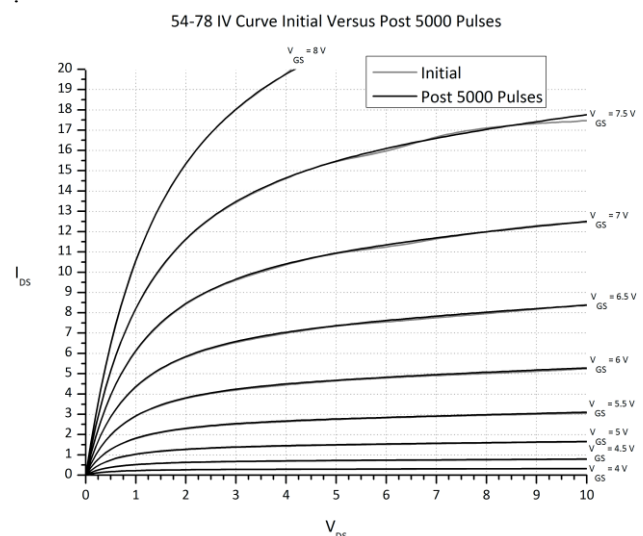


Figure 6. Output characteristic curves after 5000 shots for device 54-78.

To continue testing, the device labeled 54-88 was used at a reduced drain-to-source voltage of 600V for the first

152000 shots. Reducing the drain-to-source voltage slightly lowered the device's peak current to 250A. The external gate resistor remained the same. With the drain-to-source voltage set at 600V the device showed minimal degradation so the voltage was increased again to 1200V after executing 152000 shots. Once again the MOSFET started to show fast degradation and lasted for only 12000 additional shots.

This time the failure was different from the failure seen in the 54-78 device. Arcing started to occur between the source leads and the package's case (the drain) making further testing impossible. Figure 7 shows the arc location and Figure 8 shows the shot in which the device's package failed.

The last device of this generation, labeled 54-910, was to be subjected to high temperature testing. Initially it was briefly tested with a drain-to-source voltage of 600V to verify that it was operating properly at room temperature. Only after 100 shots, the device was taken out of the ring down test bed to be characterized. During characterization the device completely failed in the curve tracer.

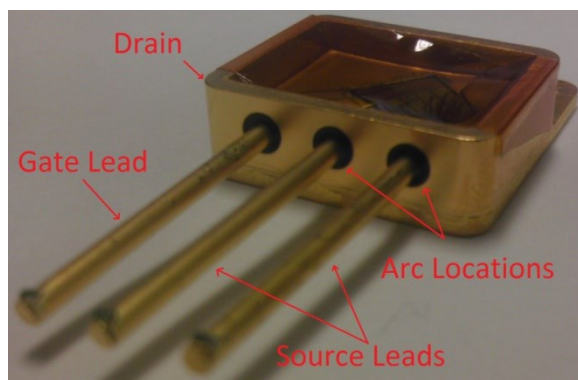


Figure 7. 54-88 device package arc locations.

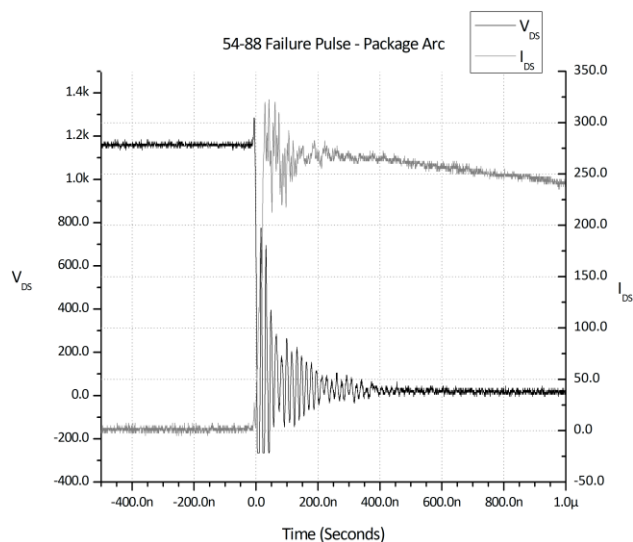


Figure 8. Failure pulse of device 54-88.

III. NEW GENERATION SIC MOSFET

Two of the newest generation of CREE's silicon carbide large area MOSFETs were designated X7Y3 and X7Y10. The first MOSFET described is the X7Y3. With this device the drain-to-source current was increased by lowering the ring down test bed's resistance. This time the device's peak current increased to 1100A. To reduce ringing on the gate the external gate resistor was increased to 20 Ohms but severe ringing was still present. Because of this, the external gate resistor was further increased to 100 Ohms. The device dissipated 900mJ with the 20 Ohms gate resistance and 1.4J with the 100 Ohms gate resistance. This amount of energy dissipated per pulse caused the device to fail into a short at approximately 2000 pulses.

During the initial characterization the device showed an impressive drain-to-source blocking voltage of 1650V even though it is only rated for 1200V. This can be seen in Figure 9.

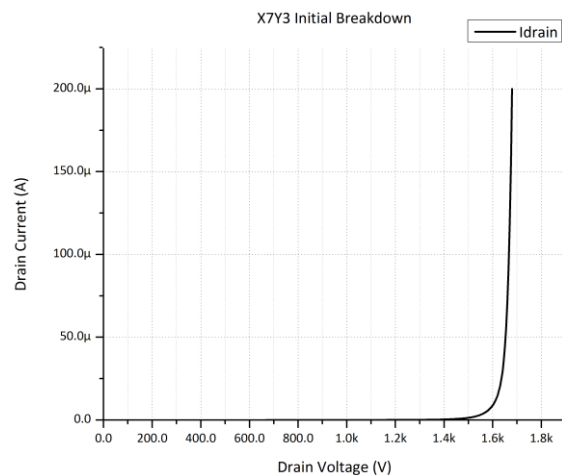


Figure 9. Initial drain-to-source breakdown voltage characterization for device X7Y3.

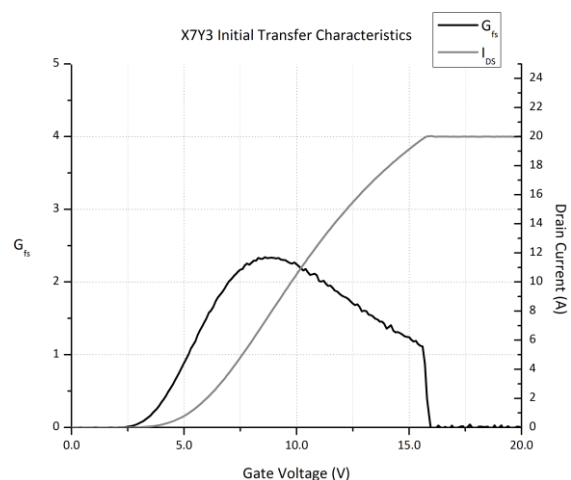


Figure 10. Initial transient characteristic curve for device X7Y3.

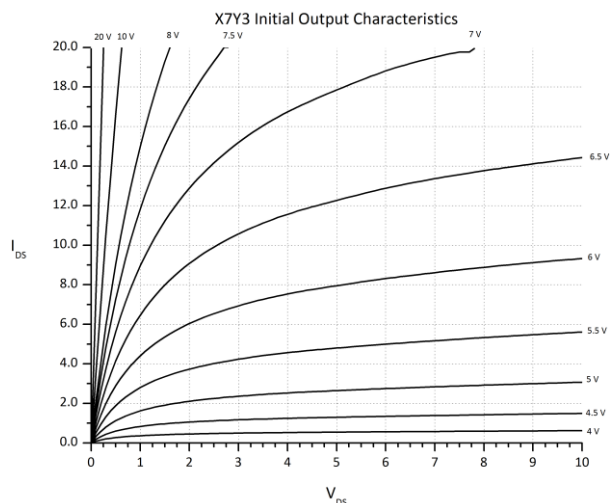


Figure 11. Initial output characteristic curves for device X7Y3.

The next device of this generation tested on the pulsed board was the X7Y10 SiC MOSFET. The device switched effectively at a gate resistance of 10 Ohms and 20 Ohms. The energy dissipated in the device with a 10 Ohms gate resistance, 900 V_{ds} and 1kA I_{ds} was 40mJ, while the energy dissipated in the device with a 20 Ohms gate resistance, 900 V_{ds} and 1kA I_{ds} was 70mJ. A switching waveform using a 20 Ohm external gate resistance is shown in Figure 12 below. The device failed shortly after on the breakdown voltage characterization. In this occasion the device is believed to have been damaged during the packaging stage.

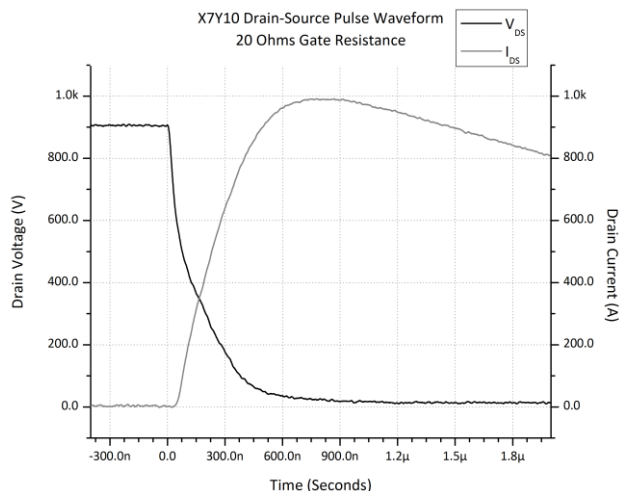


Figure 12. Switching waveform for the X7Y10 device.

IV. CONCLUSION

Testing determined that the new generation device was able to withstand a peak current pulse of 1100A, at a di/dt of 516A/μsec, and a peak current density of 2750A/cm² without saturating [2]. The previous generation was able

to withstand a peak current pulse of 270A without saturating. The increased current handling capability is due to a 17% decrease in the on resistance (R_{dsON}) with a gate bias of 20V.

V. REFERENCES

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- [2] Bayne, S.B.; Ibitayo, D., "Evaluation of SiC GTOs for pulse power switching," *Pulsed Power Conference, 2003. Digest of Technical Papers. PPC-2003. 14th IEEE International* , vol.1, no., pp.135,138 Vol.1, 15-18 June 2003